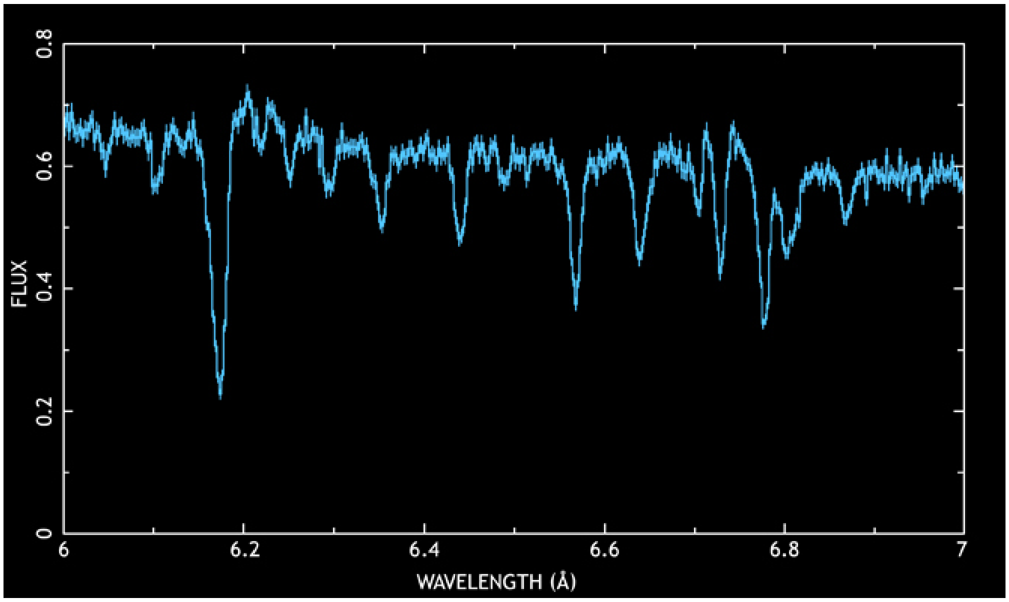
Satellite Data Results - LARGE

Large -> Black Holes -> X-ray -> Spectrometer -> Segmented

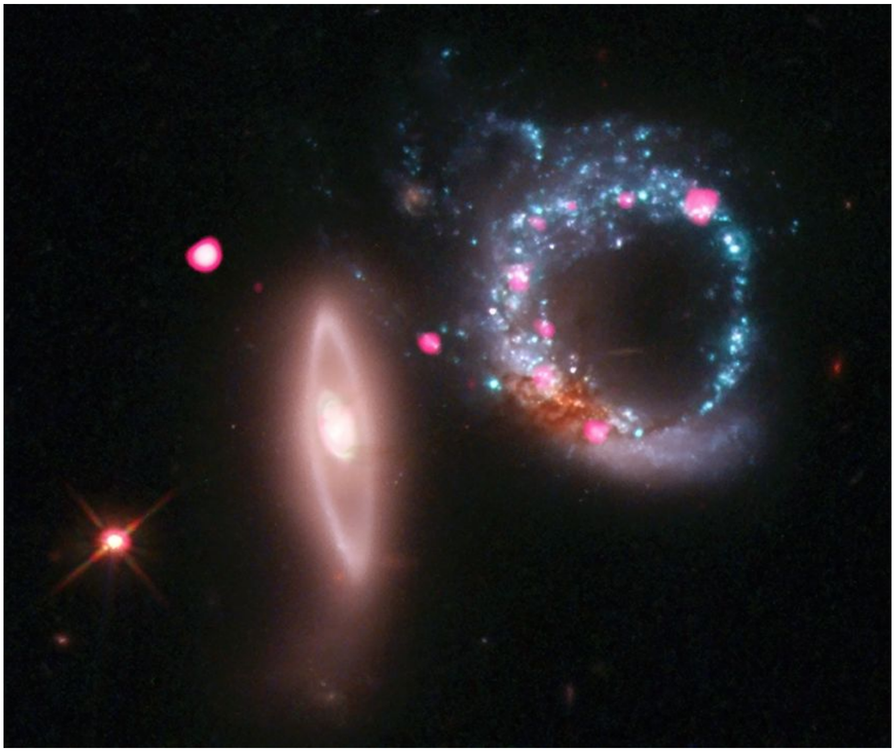


Above is real data from the Advanced CCD Imaging Spectrometer (ACIS) and the High Energy Transmission Grating Spectrometer (HETGS) on the Chandra satellite. Chandra has nested X-ray mirrors that resemble glass barrels; they are designed this way so that incoming X-rays just graze the mirrors so they can be focused. The HETGS is an assembly that is swung into position behind the mirrors where it can intercept the reflected X-rays. The X-rays are diffracted by HETGS, which changes their direction an amount dependent on the energy of the X-ray, just like a prism separates light into its component colors. The ACIS, located at the focal point of the telescope, can then detect the location of the X-ray as well as measure its energy.

The above spectrum, a graph of intensity of energy over wavelength, is of a binary star system called GRO J1655-40, which consists of a black hole pulling matter in the form of hot gas from its companion, a normal star. Most of this material is spiraling toward the black hole, creating a disk around it, though about 30% of the matter is being blown away. The dips in the spectrum show that ionized atoms of elements like oxygen and nickel in the gas around the black hole are moving away from the black hole in a high-speed wind. Magnetic forces in the disk of gas around the black hole are largely responsible for the phenomena in this case, as it is magnetic fields that are driving the winds in the disk, and magnetic friction that is heating up the inner part of the disk to the point that it emits X-rays. Understanding magnetic fields is important, and can increase our understanding, not just of star-sized black holes, but supermassive ones and even planet-forming disks around young sun-like stars.

Credit: NASA/CXC/U.Michigan/J.Miller et al.

Large -> Black Holes -> X-ray -> Camera -> Segmented
Large -> Galaxies -> X-ray -> Camera -> Segmented



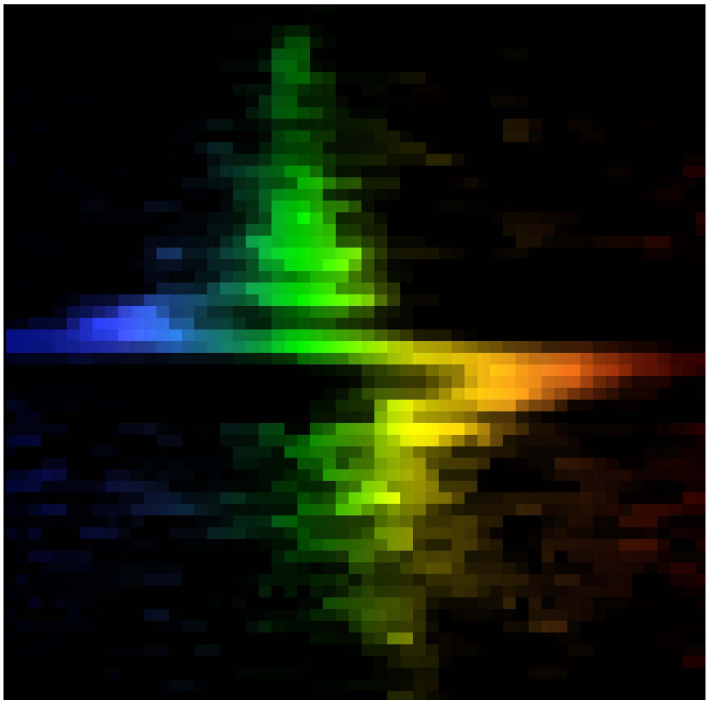
Above is real data from the Chandra X-ray Observatory Advanced CCD Imaging Spectrometer (ACIS) (in pink) and the Wide Field Planetary Camera 2 (WFPC2) on the Hubble Space Telescope with its blue, visible-light, and infrared filters represented as blue, green, and red, respectively. Known as Arp 147, this pair of gravitationally interacting galaxies consists of an elliptical galaxy (left, near center) that collided with a spiral galaxy, distorting it into a ring. The dusty reddish knot in the lower left part of the ring was probably the location of this galaxy's original nucleus. The ring of blue stars indicates a region of intense star formation, which was probably the result of shock waves caused by its close encounter with the elliptical galaxy.

Some of these new stars have sped through their evolutionary cycle in just a few million years, exploding as supernovae and leaving neutron stars and black holes behind. Neutron stars and black holes that have companion stars can become bright sources of X-rays; nine of these (in pink) are scattered around the blue ring. They are so bright in X-rays that they are must be black holes, likely with masses ten to twenty times that of the Sun.

An X-ray source was also detected in the nucleus of the red elliptical galaxy on the left, possibly a poorly-fed supermassive black hole. Other objects unrelated to Arp 147 are also visible: a foreground star in the lower left part of the image, and a background quasar visible as the pink source above and to the left of the red elliptical galaxy.

Credit: X-ray: NASA/CXC/MIT/S.Rappaport et al, Optical: NASA/STScI

Large -> Black Holes -> Optical -> spectrometer -> Single Primary
Large -> Galaxies -> Optical -> spectrometer -> Single Primary



Above is real data from the Hubble Space Telescope's Space Telescope Imaging Spectrograph (STIS). STIS is an imaging spectrograph that has the ability to simultaneously produce spectra (graphs of intensity of light over a range of wavelengths) from many points across an object like a galaxy. This spectra is of the center of the galaxy M84. The S-shape in the spectrum indicates the presence of a rapidly swirling disk of material around a central supermassive black hole. The change in wavelength, shown by a swing to the left at the top of the spectrum, is from gas in the black hole's disk that is moving towards us. Near the middle of the spectrum, gas both approaches and moves away at high speeds, which means it is orbiting close in to the black hole. Below that is a swing to the right, showing gas that is moving away from us.

This data can be used to calculate the mass of the black hole. Just as the mass of the Sun can be calculated using the laws of Newton and Kepler, the rotation speed of gas around the black hole can be used to measure the black hole's mass. STIS measured the velocity of the gas within 26 light years of the black hole to be 880,000 miles per hour (400 kilometers per second) and the black hole was calculated to be about 300 million times the mass of the sun.

Credit: Gary Bower, Richard Green (NOAO), the STIS Instrument Definition Team, and NASA

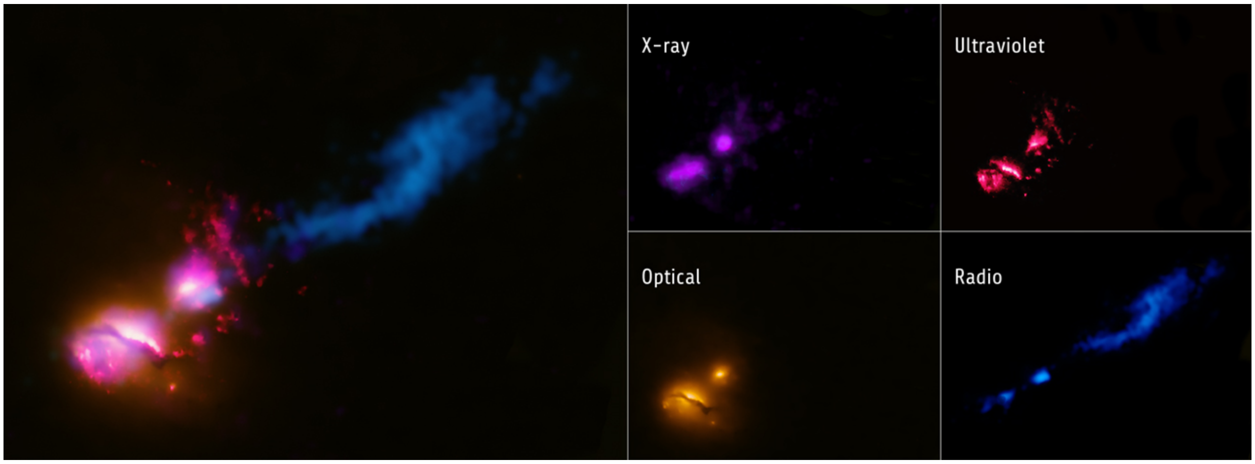
Large -> Black Holes -> Optical -> spectrometer -> Segmented
Large -> Galaxies -> Optical -> spectrometer -> Segmented

Real data from a large, visible-light space telescope with a segmented mirror does not yet exist, though it is now technologically possible to build one. Currently under construction is the James Webb Space Telescope, a telescope with a giant segmented mirror 6.5 meters (21 feet 4 inches) in diameter, made out of light-weight beryllium. (In comparison, the Hubble Space Telescope's glass mirror is 2.4 meters in diameter.) Though it will see primarily in the infrared, Webb will be able to detect red and gold visible light, and Webb's segmented, deployable design could be used to build a telescope optimized for visible light.

At left is a spectrum of the black hole at the center of the galaxy M84 from the Space Telescope Imaging Spectrograph (STIS) on the Hubble Space Telescope. The spectrum describes the motion of gas that swirls around the black hole. Telescopes like Hubble have already made amazing scientific discoveries; astronomers are very excited to see the spectacular data the next generation of telescopes, like Webb, will produce.

Credit: Gary Bower, Richard Green (NOAO), the STIS Instrument Definition Team, and NASA

Large ->Black Holes -> Optical -> camera -> Single Primary
Large ->Black Holes -> UV -> camera -> Single Primary
Large ->Galaxies -> UV -> camera -> Single Primary



Above is real data from the Hubble Space Telescope. Optical data from the Wide Field Planetary Camera 2 (WFPC 2) is in orange, and ultraviolet data from the Space Telescope Imaging Spectrograph (STIS) is in red. These data are combined with an X-ray image from Chandra (purple) and radio observations from the Very Large Array and MERLIN (blue). The object pictured, known as 3C 321, is actually a system that contains two galaxies in orbit around each other. A powerful jet from a supermassive black hole at the heart of one of the galaxies (lower left) is blasting the edge of the other galaxy (above and to its right); the impacting jet is disrupted and deflected (upper right), much like a stream of water from a hose would be if it hit a wall at an angle. The jet struck the companion galaxy relatively recently, less than about a million years ago. The violence of this, as well as the high-energy radiation produced by it, could greatly affect any planets in its path, damaging their atmospheres; however, the jet could also trigger a burst of star formation in its wake, which could one day mean new planets.

Each wavelength shows a different aspect of this event. The X-ray data provides evidence that each galaxy contains a rapidly growing supermassive black hole at its center. The Hubble ultraviolet data shows large quantities of warm and hot gas in the vicinity of the galaxies, indicating the supermassive black holes in both galaxies have had a violent past. Hubble's visible light image shows the glow from the stars in each galaxy. A bright spot in the radio image shows where the jet struck the side of the galaxy, about 20,000 light-years from the main galaxy, dissipating some of its energy. The radio data also shows that the jet stretches some 850,000 light years past the galaxy it impacted.

Credit: X-ray: NASA/CXC/CfA/D.Evans et al.; Optical/UV: NASA/STScI; Radio: NSF/VLA/CfA/D.Evans et al., STFC/JBO/MERLIN

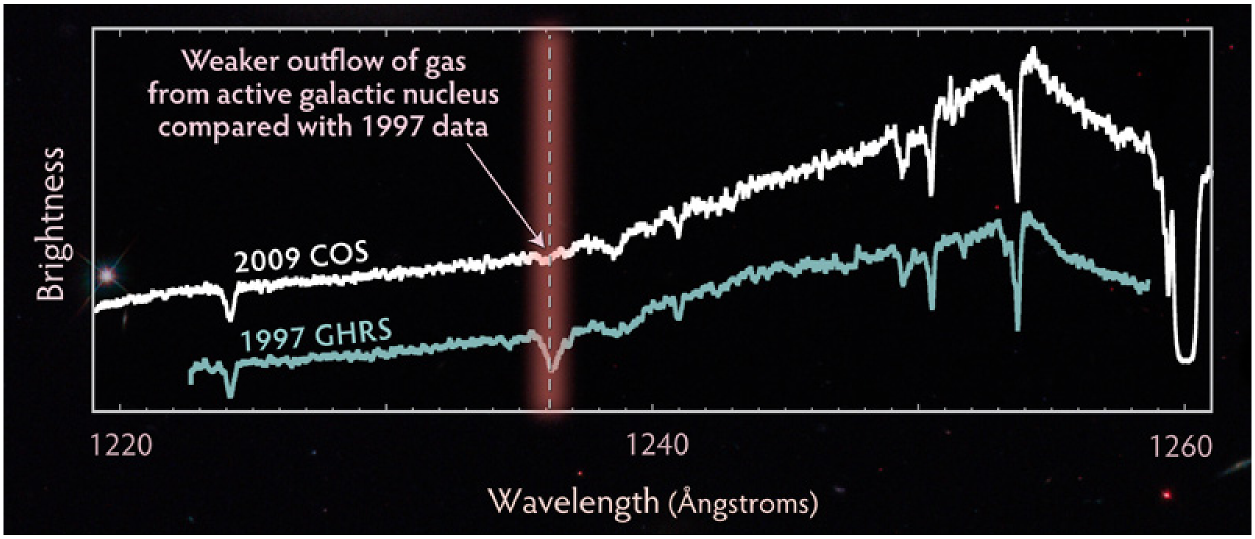
Large ->Black Holes -> Optical -> camera -> Segmented
Large ->Black Holes -> UV -> camera -> Segmented
Large ->Galaxies -> UV -> camera -> Segmented

Real data from a large ultraviolet or visible-light space telescope with a segmented mirror does not yet exist, though it is now technologically possible to build one. Currently under construction is the James Webb Space Telescope, a telescope with a giant segmented mirror 6.5 meters (21 feet 4 inches) in diameter, made out of light-weight beryllium. (In comparison, the Hubble Space Telescope's glass mirror is 2.4 meters in diameter.) Though it will see primarily in the infrared, Webb will be able to detect red and gold visible light. Webb's segmented, deployable design could also be used to build a telescope optimized for visible or ultraviolet light.

Above is a multiwavelength image of 3C 321, including optical and ultraviolet data from the Hubble Space Telescope's Wide Field Planetary Camera 2 (WFPC 2) and Space Telescope Imaging Spectrograph (STIS), respectively. 3C 321 is a system of orbiting galaxies; a jet from the black hole at the center of one of them is blasting the other. Visible wavelengths show the glow from the stars in the galaxies (in orange), and large quantities of warm and hot gas in the vicinity are visible in the ultraviolet (in red). (Additional radio data in blue traces the path of the jet, and X-ray data from Chandra in purple highlights the presence of supermassive black holes at the center of both galaxies.) Telescopes like Hubble have already made amazing scientific discoveries; astronomers are very excited to see the spectacular data the next generation of telescopes, like Webb, will produce.

Credit: X-ray: NASA/CXC/CfA/D.Evans et al.; Optical/UV: NASA/STScI; Radio: NSF/VLA/CfA/D.Evans et al., STFC/JBO/MERLIN

Large -> Black Holes -> UV -> spectrometer -> Single Primary
Large -> Galaxies -> UV -> spectrometer -> Single Primary

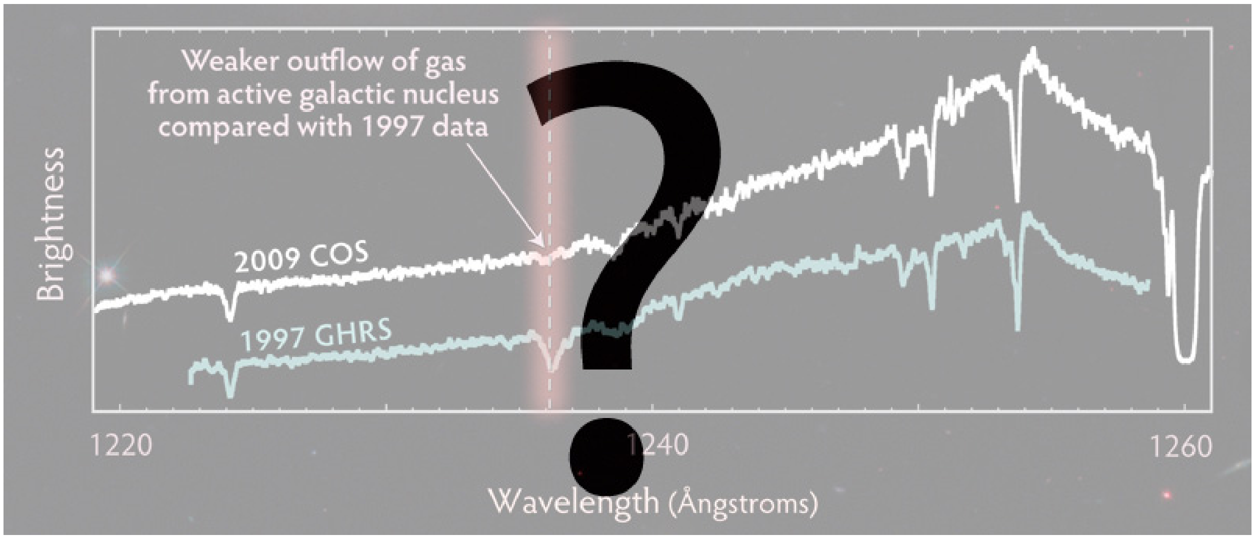


Above is real data from the Cosmic Origins Spectrograph (COS) onboard the Hubble Space Telescope. These spectra show the intensity of light over ultraviolet wavelengths of Markarian 817, a spiral galaxy with a supermassive black hole at its center, that is explosively expelling matter into space at 9 million miles an hour. When observations from COS in 2009 (top) were compared with data from the Goddard High Resolution Spectrograph (GHRS) taken in 1997 (bottom), scientists learned that a hydrogen gas cloud present in 1997 had disappeared, likely in an outflow of material from the galaxy.

Powerful winds caused by streams of charged particles in the disk of matter around the black hole are responsible for blowing material away. Some of it becomes intergalactic gas, while some of it rains back onto the galaxy. The material being expelled contains atoms of elements like carbon, nitrogen, and oxygen, and the signatures of these elements are contained in spectra. Astronomers can use these spectra to understand the motion of the outflowing material, including how much of it escapes and how much is recaptured by the galaxy. The composition, location, and dynamics of the winds that distribute the material can also be determined.

Credit: NASA, ESA, and the Hubble SM4 ERO Team

Large -> Black Holes -> UV -> spectrometer -> Single Primary

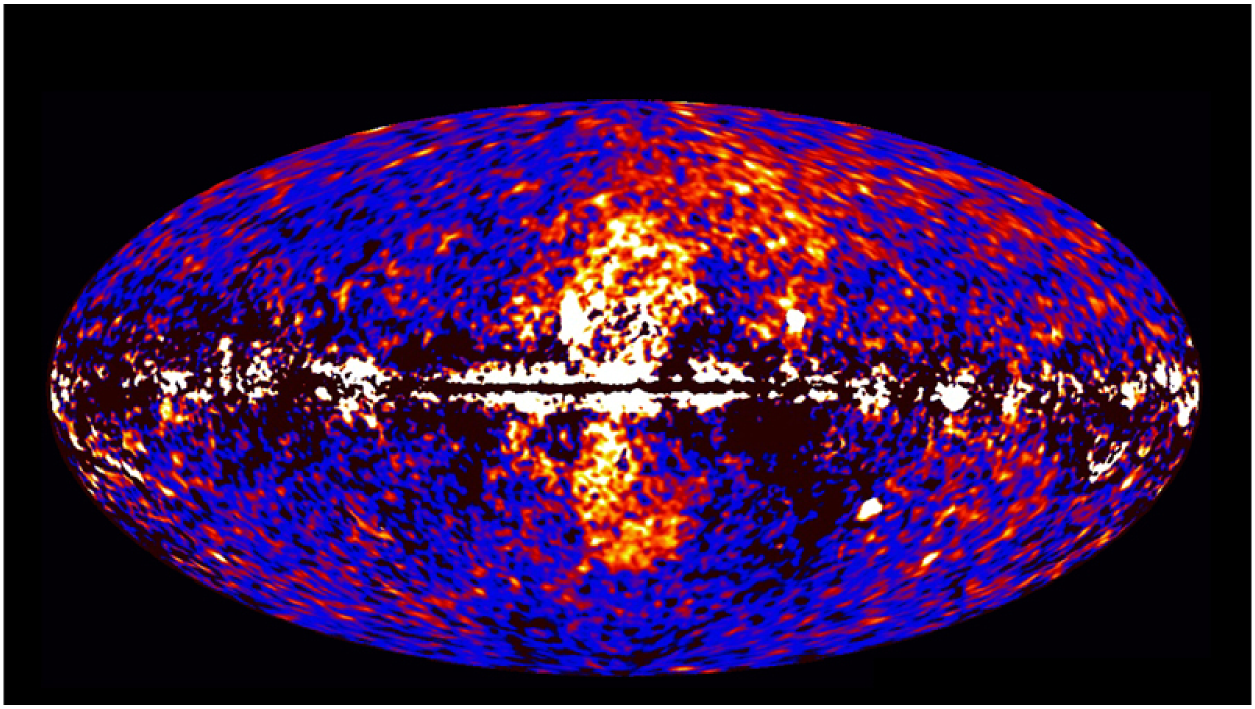


Real data from a large, ultraviolet space telescope with a segmented mirror does not yet exist, though it is now technologically possible to build one. Currently under construction is the James Webb Space Telescope, a telescope with a giant segmented mirror 6.5 meters (21 feet 4 inches) in diameter, made out of light-weight beryllium. (In comparison, the Hubble Space Telescope's glass mirror is 2.4 meters in diameter.) Though it will see primarily in the infrared, Webb's segmented, deployable design could also be used to build a telescope optimized for ultraviolet light.

Shown above is 2009 data from the Cosmic Origins Spectrograph (COS) onboard the Hubble Space Telescope, compared with older Goddard High Resolution Spectrograph (GHRS) data from 1997. Both spectra show the intensity of light over ultraviolet wavelengths of Markarian 817, a spiral galaxy with a supermassive black hole at its center, that is explosively expelling matter into space at 9 million miles an hour. An ultraviolet telescope with a large, segmented mirror and sensitive detectors could further refine these data results with more detailed spectra. Telescopes like Hubble have already made amazing scientific discoveries; astronomers are very excited to see the spectacular data the next generation of telescopes, like Webb, will produce.

Credit: NASA, ESA, and the Hubble SM4 ERO Team

Large ->Galaxies -> gamma-ray -> scintillator
Large ->Black Holes -> gamma-ray -> scintillator



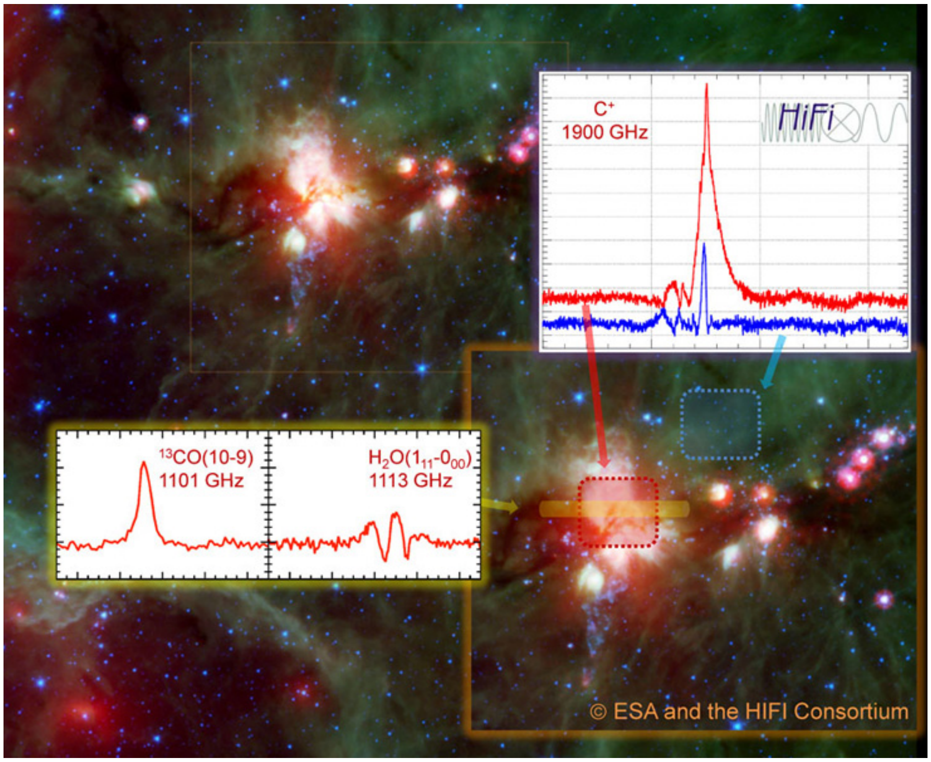
Above is real data from the Large Area Telescope (LAT) onboard the Fermi Gamma-ray Space Telescope. This gamma-ray, all-sky map shows a previously unseen large-scale structure that was discovered by Fermi in 2010. Visible on this image as a dumbbell shaped feature (in yellow/orange) emerging from the galactic center, extending 25,000 light-years north and south from the plane of the Milky Way, are what appear to be large gamma-ray emitting bubbles.

These bubbles were previously undetected, partly because of a fog of gamma rays that appears throughout the sky. The fog happens when particles moving near the speed of light interact with light and interstellar gas in the Milky Way. However, the LAT team was able to detect these giant features due to the LAT's high resolution (which was the highest of any gamma-ray detector at the time) and their continued efforts to refine their models to remove the effects of the gamma-ray fog from their data.

Scientists now are conducting more analyses to better understand how the never-before-seen structure was formed. The bubble emissions are much more energetic than the gamma-ray fog and also appear to have well-defined edges. The structure's shape and emissions suggest that it was formed as a result of a large and relatively rapid energy release - the source of which remains a mystery. One theory is that the bubbles are a remnant of a past eruption from a supermassive black hole at the center of our galaxy. While there is no evidence that the Milky Way's black hole has a jet today, it may have in the past. Another theory is that the bubbles may have formed as a result of gas flowing out from a burst of star formation, perhaps the one that produced many massive star clusters in the Milky Way's center several million years ago.

Credit: NASA/DOE/Fermi LAT/D. Finkbeiner et al.

Large ->Star Formation -> IR -> spectrometer -> Single Primary



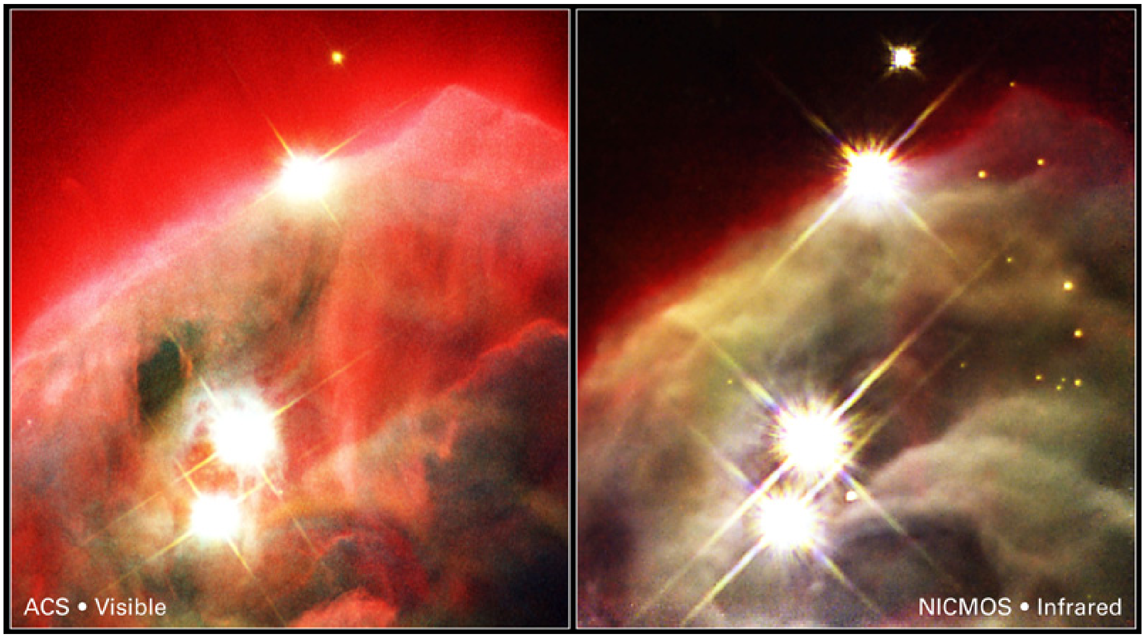
Above is real data from the Heterodyne Instrument for the Far Infrared (HIFI) on the European Space Agency's Herschel satellite, a far-infrared and submillimeter mission that at the time of its launch in 2009, was the largest telescope to be put into space. This spectrum, or graph of intensity over a range of wavelengths, is some of the first data produced by Herschel, and was a test of its capabilities.

The image (which was captured by the infrared Spitzer Space Telescope) and the HIFI spectra show the first object observed by HIFI - DR 21, a star-forming region in our Milky Way about 6000 light years away. In the image, emission from large molecules glows green due to the nearby, newly-formed massive stars.

The blue and red boxes on the inset image (which itself is outlined in orange) show an area that has been surveyed for ionized carbon. A new star is present within the red box. The spectrum of that region (the red line in the top graph) shows the presence of a powerful wind that is ripping the gas cloud apart. By contrast, the region in the blue box has not yet been disturbed by this star (the blue line in the top graph). The yellow stripe through the red box shows where HIFI found evidence of carbon monoxide (far side of red spectrum at left) and water molecules (near side). The large width of the carbon monoxide peak and the shape of the water spectrum indicate that this material is part of a massive outflow from the newly formed star.

Credit: ESA and the HIFI Consortium, (background) NASA/Sptizer

Large ->Star Formation -> IR -> camera -> Single Primary
Large ->Star Formation ->Optical -> camera -> Single Primary



Above is real data from the Advanced Camera for Surveys (ACS) and the Near Infrared Camera and Multi-Object Spectrometer (NICMOS) onboard the Hubble Space Telescope. The visible light image at left and the near-infrared image at right give slightly different views of the star-forming region known as the Cone Nebula (NGC 2264). The four large, bright stars are visible in both infrared and visible light images because they are in front of the nebula. The smaller yellow stars are, however, visible only in infrared light because they are either behind the nebula or embedded in it. Infrared light is needed in order to study stars that are hidden by dusty clouds that are opaque to visible light, particularly because it is in these regions that stars are born. The Cone Nebula is so dense that NICMOS can only see half a light-year deep into the seven light-years-long nebula. It is in the thickest dust that the youngest stars are forming.

The Cone resides in a turbulent star-forming region, located 2,500 light-years away in the constellation Monoceros inside our own Milky Way galaxy. Radiation from hot, nearby young stars (not shown) has slowly eroded the nebula over millions of years.

Credit: (NICMOS image) NASA, the NICMOS Group (STScI, ESA), and the NICMOS Science Team (University of Arizona). (ACS image) NASA, H. Ford (JHU), G. Illingworth (UCSC/LO), M.Clampin (STScI), G. Hartig (STScI), the ACS Science Team, and ESA

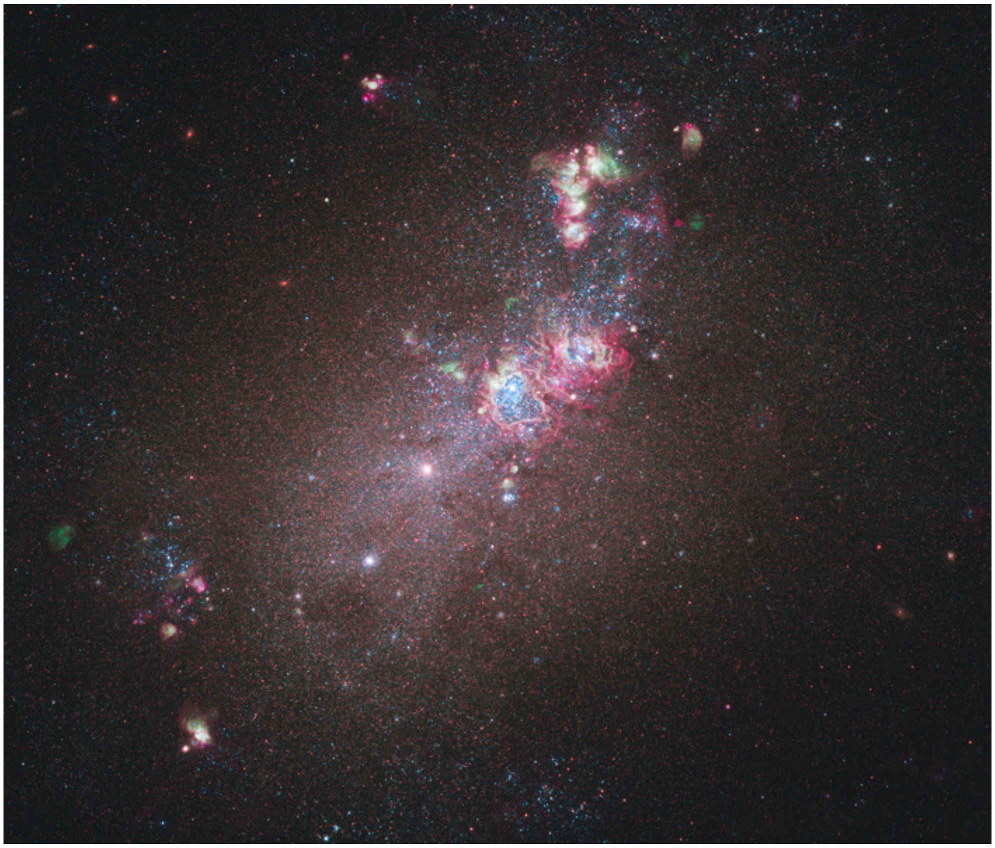
Large ->Star Formation -> IR -> spectrometer -> segmented
Large ->Star Formation -> IR -> camera -> segmented

Real data from a large, infrared space telescope with a segmented mirror does not yet exist, though it will in the near future. Currently under construction is the James Webb Space Telescope, an infrared mission with a segmented mirror 6.5 meters (21 feet 4 inches) in diameter, made out of light-weight beryllium. (In comparison, the Hubble Space Telescope's glass mirror is 2.4 meters in diameter.) Hubble can see a small portion of the near-infrared part of the electromagnetic spectrum, but a larger mirror and longer infrared wavelength capabilities are needed to see deep into the thick dust clouds where stars are being born. With its superior imaging and spectroscopic abilities, Webb will give astronomers their closest look yet at star formation.

The above image is from a computer model that represents astronomers' best ideas about the star formation process within a dusty nebula. Redder colors indicate thicker dust. The pinwheel near the center is a protostar, perhaps 10,000 years old. Protostars arise when a dense knot of dust less than a light-year across collapses, but the details of the process are not well known. With Webb currently under construction, space telescopes with giant mirrors are becoming a reality; astronomers are eager to see the spectacular data the next generation of telescopes, like Webb, will produce.

Credit: NCSA/NASA/A. Kritsuk and M. Norman (UC San Diego) and A. Boley (Univ. of Florida)

Large ->Star Formation -> UV -> camera -> single primary

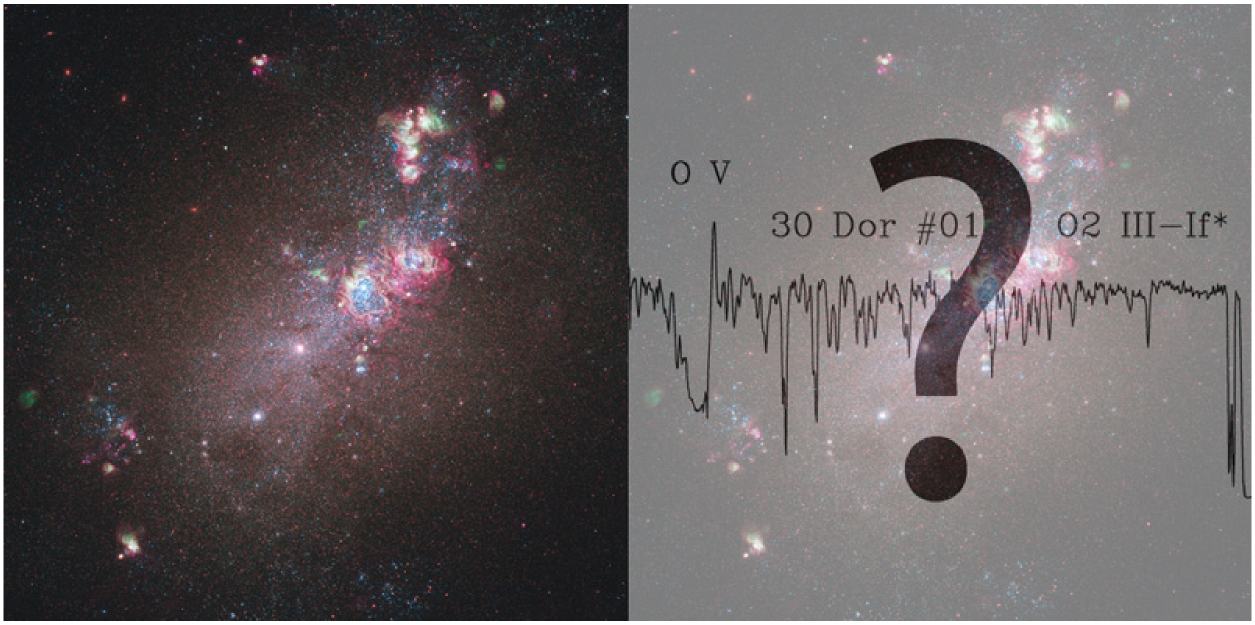


Above is real data from the Wide Field Camera 3 (WFC3) onboard the Hubble Space Telescope. This image of nearby dwarf galaxy NGC 4214 uses both ultraviolet and visible-light filters. The regions of star formation in this galaxy glow because of the strong ultraviolet light emitted from young stars. Hot winds from these young stars blow out into the surrounding gas at millions of miles an hour, which causes bubbles to form. One example of this is near the center of the galaxy, where a giant gas bubble surrounds hundreds of massive blue stars, each more than 10,000 times brighter than our Sun. The bubble will increase in size as the most massive stars in the center reach the ends of their lives and explode as supernovae.

Though NGC 4214 is small and irregularly shaped, it is nearby and thus provides a unique view of star formation in galaxies other than the Milky Way. The visible-light filters reveal the light from older star populations and the overall structure of the galaxy, and can also be used to detect the presence of specific gases such as hydrogen, nitrogen, and oxygen.

Credit: NASA, ESA, and the Hubble Heritage (STScI/AURA)-ESA/Hubble Collaboration

Large ->Star Formation -> UV -> camera -> segmented
Large ->Star Formation -> UV -> spectrometer -> segmented
Large ->Star Formation -> Optical -> camera -> segmented
Large ->Galaxies -> UV -> spectrometer -> segmented

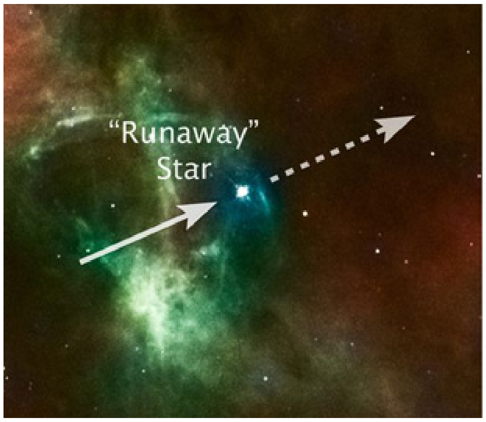


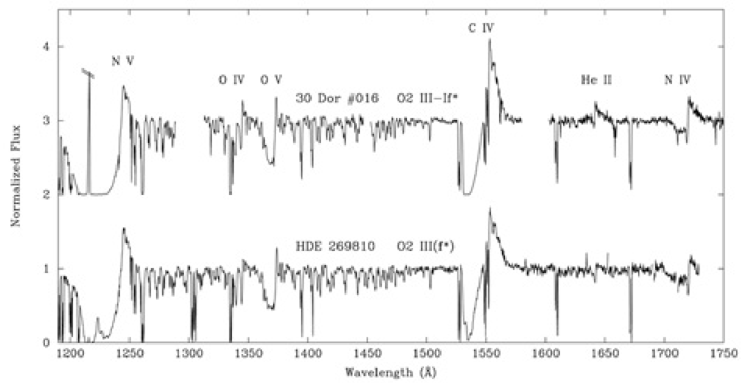
Real data from a large, ultraviolet or visible-light space telescope with a segmented mirror does not yet exist, though it is now technologically possible to build one. Currently under construction is the James Webb Space Telescope, an infrared telescope with a giant, segmented mirror 6.5 meters (21 feet 4 inches) in diameter, made out of light-weight beryllium. (In comparison, the Hubble Space Telescope's glass mirror is 2.4 meters in diameter.) Webb will see the universe in infrared light, however its segmented, deployable design could also be used to build a telescope optimized for visible or ultraviolet light.

At left is a ultraviolet/visible light image of star formation in the small, nearby dwarf galaxy NGC 4214, which was captured by Hubble's Wide Field Camera 3 (WFC3). The regions of star formation in this galaxy glow because of the strong ultraviolet light emitted from young stars. A telescope with a much bigger mirror would reveal things never-before-seen and make unprecedented discoveries. With Webb currently under construction, space telescopes with giant mirrors are becoming a reality; astronomers are eager to see the spectacular data the next generation of telescopes, like Webb, will produce.

Credit: (left and right) NASA, ESA, and the Hubble Heritage (STScI/AURA)-ESA/Hubble Collaboration
(spectrum, right) NASA, ESA, and C. Evans, et al. (from The Astrophysical Journal, vol. 715, p. L74, 2010)

Large ->Star Formation -> UV -> spectrometer -> Single Primary





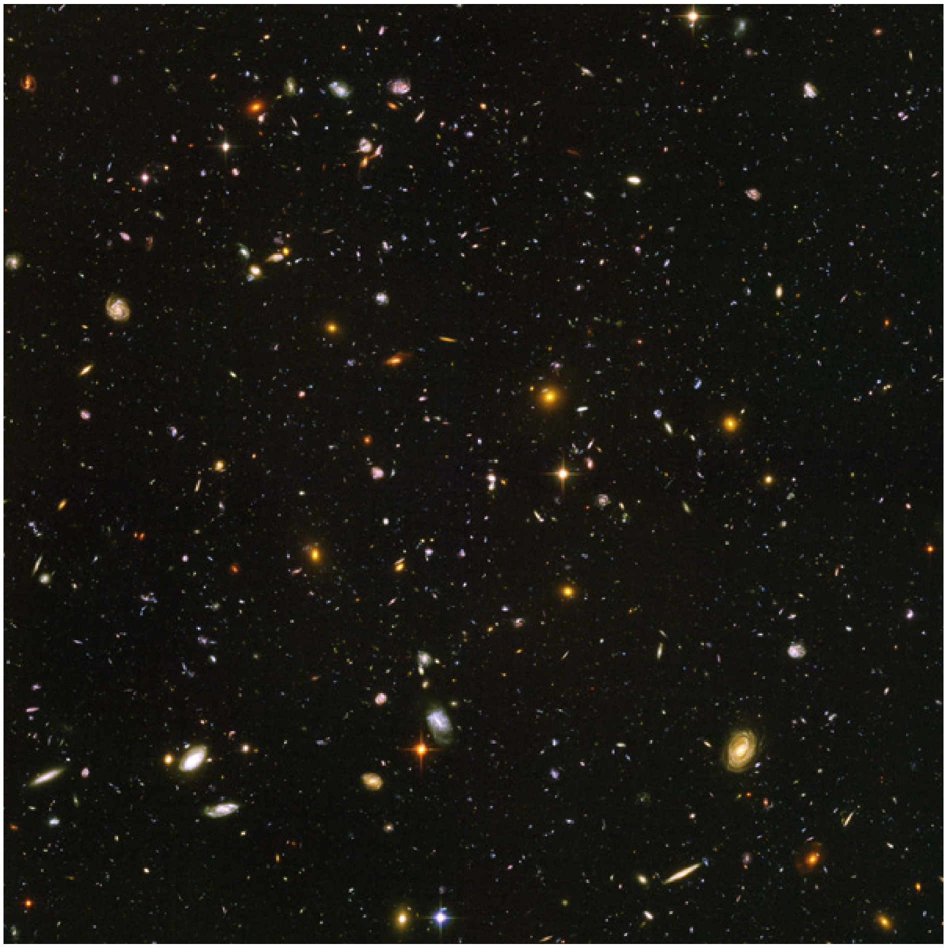
Above is real data from the Hubble Space Telescope. On the left is an image taken by Hubble's Wide-Field Planetary Camera 2 (WFPC 2) and on the right are spectra from the Cosmic Origins Spectrograph (COS) and the Space Telescope Imaging Spectrograph (STIS). These ultraviolet spectra, or graphs of intensity of energy over wavelength, compare two stars, both in the Large Magellanic Cloud, an irregular galaxy near to our own. The top graph is COS data of a massive star called 30 Dor 016 and the bottom one is STIS data of a similar star, HDE 269810. Both of these stars are "runaway" stars - stars that are seen traveling at high speeds and have been ejected from their birthplaces.

30 Dor 016, shown in the Hubble image above, is about 90 times more massive than our sun, and is whipping through space at 250,000 miles (400,000 kilometers) an hour. It appears to already have traveled some 375 light-years from its place of birth, a star cluster called R136, located deep in the 30 Doradus (or Tarantula) Nebula. This star is very young, only 1-2 million years old, and it appears to have been kicked out of its birthplace by a group of even bigger sibling stars. Astronomers can tell the star is moving quickly because features in the spectra of 30 Dor 016 show that its stellar winds are blowing at very fast speeds, the fastest yet seen for a runaway star.

Runaway stars can be created in a few ways. A star can be ejected from its birthplace by an encounter with one or two heavier siblings, or a star may get a 'kick' from a supernova explosion. Because the R136 star-forming region is so young, the cluster's most massive stars haven't gone through their life cycles and exploded as supernovae yet, so most likely 30 Dor 016 was ejected through interaction with other stars.

Credit: (image) J. Walsh and Z. Levay, ESA/NASA (spectra) NASA, ESA, and C. Evans, et al. (from The Astrophysical Journal, vol. 715, p. L74, 2010)

Large -> Early Universe -> Optical -> Camera -> Single Primary

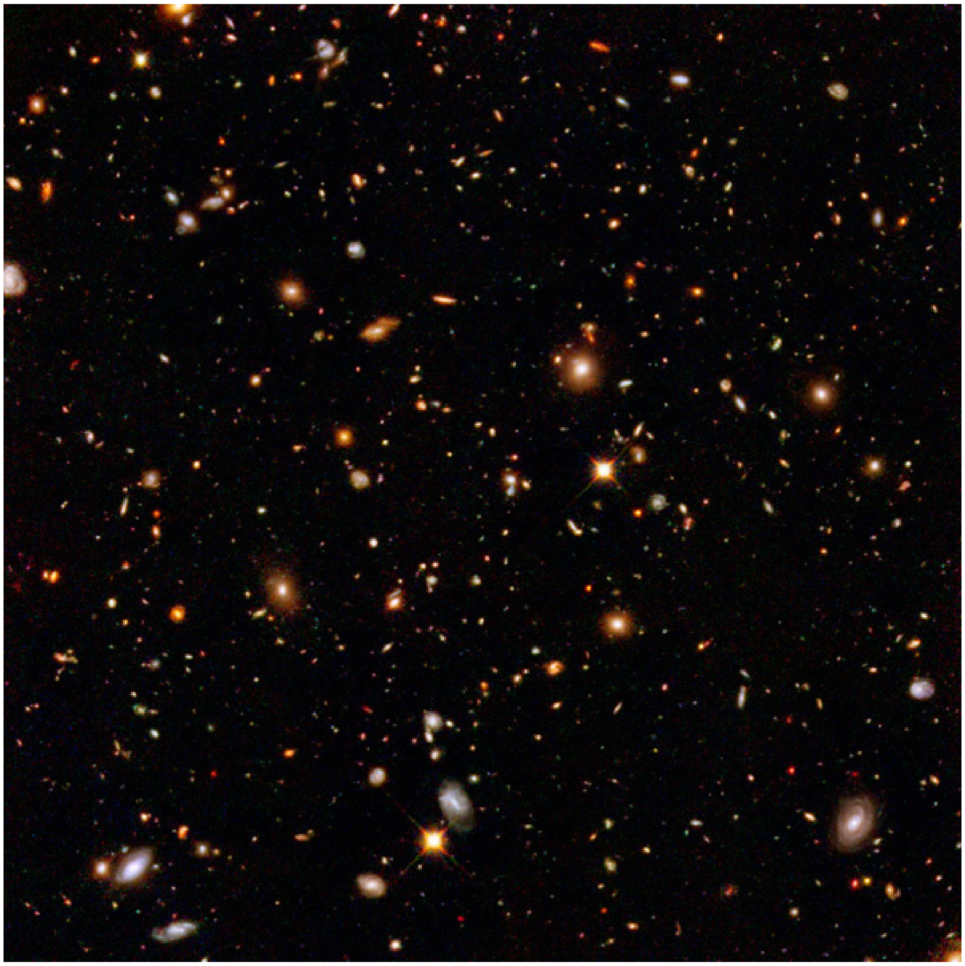


Above is real data from the Advanced Camera for Surveys (ACS) on the Hubble Space Telescope. This image is known as the Hubble Ultra Deep Field (HUDF) and is a million-second-long exposure that reveals the the most distant galaxies ever to be seen in visible light, offering insights into what types of objects existed in the universe long ago. This tiny patch of sky - much less than the area the full moon covers on the sky - reveals over 10,000 galaxies, many of which existed when the universe was only a fraction of its present age. A wide range of galaxies of various sizes, shapes, and colors are present here, some of them oddly shaped, and some apparently interacting with each other. Their strange shapes are a far cry from the majestic spiral and elliptical galaxies we see today. These oddball galaxies chronicle a period when the universe was more chaotic and order and structure were just beginning to emerge.

This HUDF image is visible-light, though Hubble also captured a spectacular infrared view of the same field of galaxies.

Credit: NASA, ESA, S. Beckwith (STScI) and the HUDF Team

Large -> Early Universe -> IR -> Camera -> Single Primary



Above is real data from the Near Infrared Camera and Multi-object Spectrometer (NICMOS) on the Hubble Space Telescope.   This image is known as the Hubble Ultra Deep Field (HUDF) and is a million-second-long exposure that reveals the the most distant galaxies ever to be seen in visible light, offering insights into what types of objects existed in the universe long ago. This tiny patch of sky - much less than the area the full moon covers on the sky - reveals over 10,000 galaxies, many of which existed when the universe was only a fraction of its present age. A wide range of galaxies of various sizes, shapes, and colors are present here, some of them oddly shaped, and some apparently interacting with each other.   Their strange shapes are a far cry from the majestic spiral and elliptical galaxies we see today. These oddball galaxies chronicle a period when the universe was more chaotic and order and structure were just beginning to emerge.

This HUDF image is near-infrared, though Hubble also captured a spectacular visible-light view of the same field of galaxies.

Credit: NASA, ESA, and R. Thompson (Univ. Arizona)

Large ->Early Universe -> Optical -> Camera -> Segmented
Large ->Galaxies -> Optical -> Camera -> Segmented

Real data from a large, visible-light space telescope with a segmented mirror does not yet exist, though it is now technologically possible to build one. Currently under construction is the James Webb Space Telescope, a telescope with a giant segmented mirror 6.5 meters (21 feet 4 inches) in diameter, made out of light-weight beryllium. (In comparison, the Hubble Space Telescope's glass mirror is 2.4 meters in diameter.) Though it will see primarily in the infrared, Webb will be able to detect red and gold visible light, and Webb's segmented, deployable design could be used to build a telescope optimized for visible light.

With its superior imaging and spectroscopic abilities, Webb will be able to look further back into the past than ever before, to see the first stars and galaxies that formed in the early universe. Because Webb is optimized for the infrared, it will be able to see the part of the spectrum where the most distant and earliest galaxies shine. Hubble sees "toddler" galaxies - Webb will see newborns.

The earliest galaxies were small dwarfs, smaller even than the galaxies that Hubble has seen (above left, visible-light view) in its Ultra Deep Field. One way astronomers think galaxies grew was by colliding and merging with other small galaxies, and over billions of years these mergers built up the giant galaxies we see today. Mergers triggered pulses of star formation that created the elements necessary for planets, and ultimately, life. Astronomers are eager to see the spectacular data the next generation of telescopes, like Webb, will produce.

Credit: NASA, ESA, S. Beckwith (STScI) and the HUDF Team

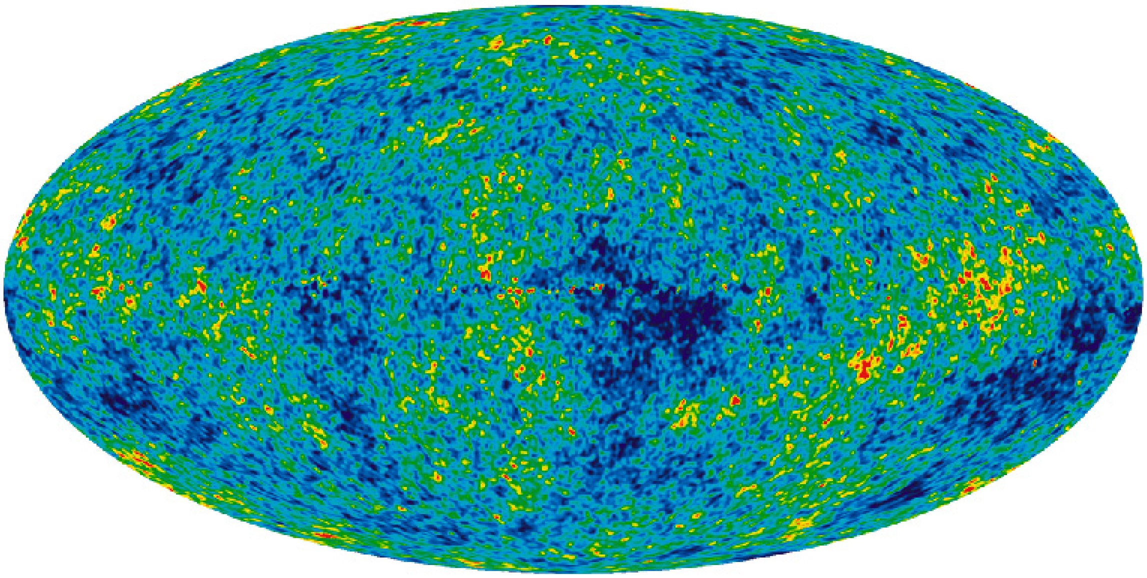
Large ->Early Universe -> IR -> Camera -> Segmented
Large ->Early Universe -> IR -> Spectrometer -> Segmented
Large ->Galaxies -> IR -> camera -> Segmented
Large ->Galaxies -> IR -> Spectrometer -> Segmented

Real data from a large, infrared space telescope with a segmented mirror does not yet exist, though it will in the near future. Currently under construction is the James Webb Space Telescope, an infrared mission with a giant segmented mirror 6.5 meters (21 feet 4 inches) in diameter, made out of light-weight beryllium. (In comparison, the Hubble Space Telescope's glass mirror is 2.4 meters in diameter.) With its superior imaging and spectroscopic abilities, Webb will be able to look further back into the past than ever before, to see the first stars and galaxies that formed in the early universe. Because Webb is optimized for the infrared, it will be able to see the part of the spectrum where the most distant and earliest galaxies shine. Hubble sees "toddler" galaxies - Webb will see newborns.

The earliest galaxies were small dwarfs, smaller even than the galaxies that Hubble has seen (above left, near-infrared view) in its Ultra Deep Field. One way astronomers think galaxies grew was by colliding and merging with other small galaxies, and over billions of years these mergers built up the giant galaxies we see today. Mergers triggered pulses of star formation that created the elements necessary for planets, and ultimately, life. Astronomers are eager to see the spectacular data the next generation of telescopes, like Webb, will produce.

Credit: (left) NASA, ESA, and R. Thompson (Univ. Arizona)
(right) NASA (overlay) ESA/Herschel/SPIRE "Nearby Galaxies" consortium

Large ->Early Universe -> Microwave -> radiometer

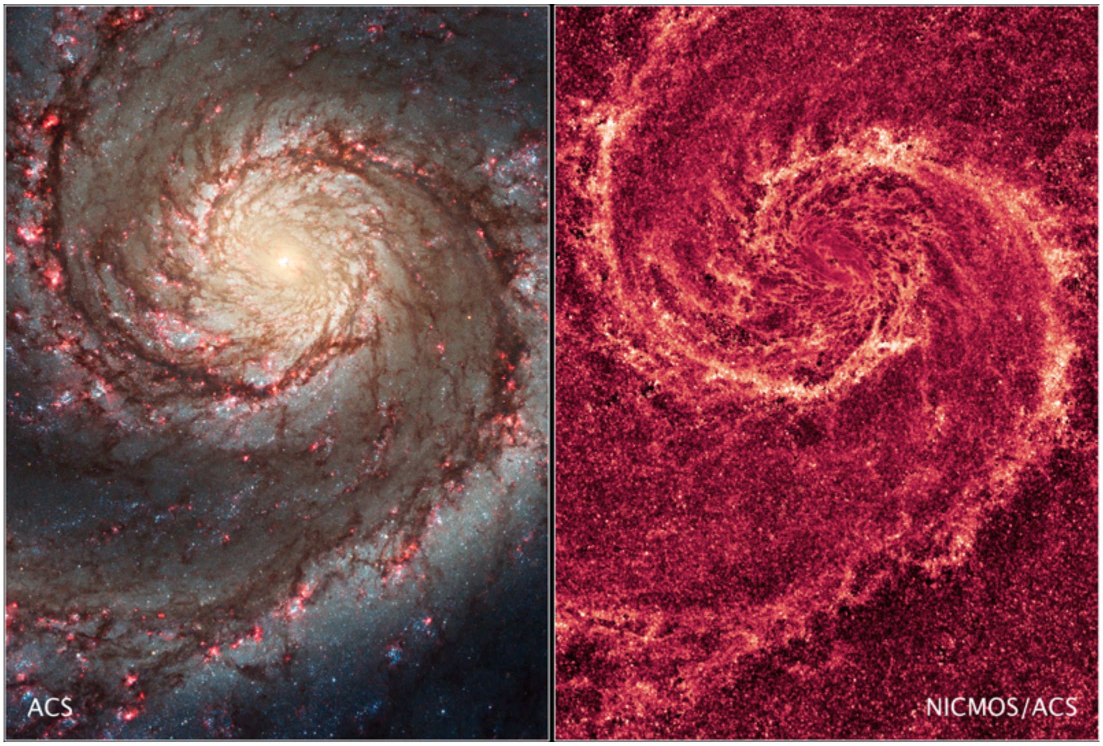


Above is real data from the Wilkinson Microwave Anisotropy Probe (WMAP), a cosmology satellite that was launched in 2001. Though its predecessor, COBE, had several instruments, WMAP's only instrument is a pair of radiometers. WMAP's goal is to measure the temperature differences in the cosmic microwave background (CMB) radiation, the radiation released after the Big Bang but long before the formation of galaxies, when the universe was less than 400,000 years old. These "anisotropies", or temperature differences, are used to measure the universe's geometry, content, and evolution, as well as to test the Big Bang Theory.

The above detailed, all-sky picture of the infant universe was created from seven years of WMAP data. The image reveals 13.7 billion year-old temperature fluctuations (shown as color differences) that correspond to the seeds that grew to become the galaxies.

Credit: NASA / WMAP Science Team

Large ->Galaxies -> IR -> camera -> Single Primary
Large ->Galaxies ->Optical -> camera -> Single Primary



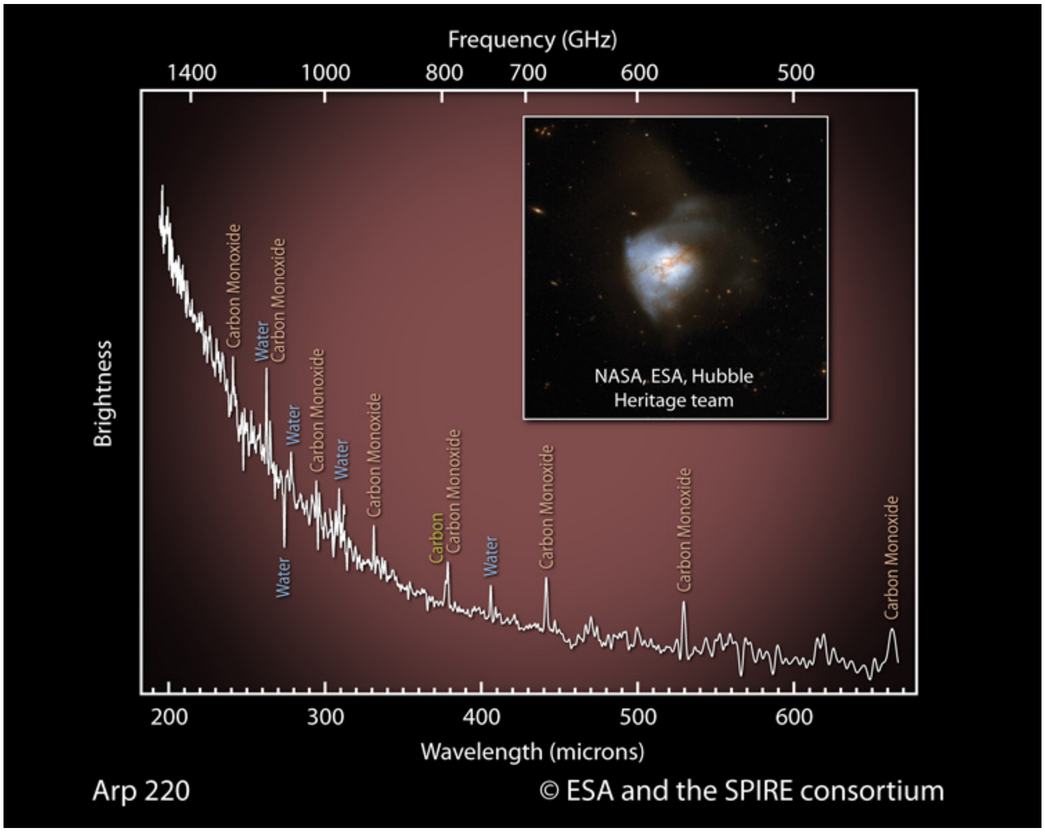
Above is real data from the Advanced Camera for Surveys (ACS) and the Near Infrared Camera and Multi-Object Spectrometer (NICMOS) onboard the Hubble Space Telescope. Both images show a face-on view of the spiral galaxy, M51, also known as the Whirlpool. At left, visible light reveals the galaxy's curved arms, pink star-forming regions, and bright blue star clusters.

In the near-infrared image at right, most of the starlight has been removed, revealing the Whirlpool's skeletal dust structure. The red color in the near-infrared image traces the dust, which is punctuated by hundreds of tiny clumps of stars, each about 65 light-years wide and never-before-seen. These star clusters cannot be seen in visible light because of the opaque, dense dust that surrounds them. Despite these tiny clumps, the dust largely lies in smooth lanes, something that surprised astronomers, who had expected to see large, 100-300 light-year-wide dust clouds. In this case, an encounter with another galaxy may have prevented giant clouds from forming.

The ability to probe the dust structure of a galaxy is important, as it provides astronomers with invaluable information on how the gas and dust collapse to form stars. Although Hubble is providing amazing views of the internal structure of galaxies such as M51, the upcoming James Webb Space Telescope (with its giant, segmented mirror) will show us even more detail about dusty galaxies, much further into the infrared part of the electromagnetic spectrum.

Credit: (ACS) NASA, ESA, S. Beckwith (STScI), and the Hubble Heritage Team (STScI/AURA)
(NICMOS) NASA, ESA, M. Regan and B. Whitmore (STScI), and R. Chandar (University of Toledo)

Large ->Early Universe -> IR -> Spectrometer -> Single Primary
Large ->Galaxies -> IR -> Spectrometer -> Single Primary

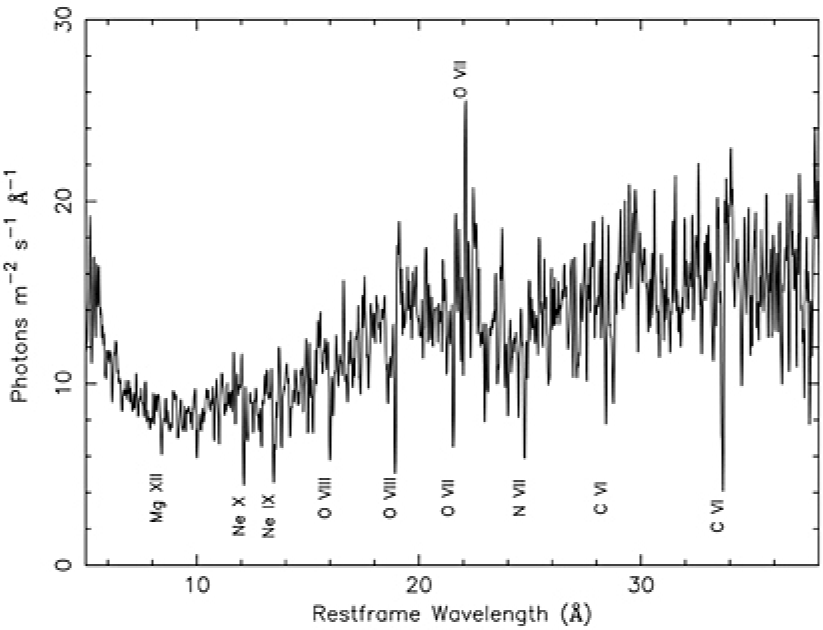


Above is real data from the Spectral and Photometric Imaging Receiver (SPIRE) instrument on the European Space Agency's Herschel Space Telescope, a far-infrared and submillimeter mission that at the time of its launch in 2009, was the largest telescope to be put into space. This spectrum, or graph of intensity over a range of infrared wavelengths, shows the presence of carbon monoxide (CO) and water (H_2O) in the galaxy Arp 220. Located 250 million light years away, Arp 220 has very active star formation that was triggered when two large spiral galaxies collided. When two galaxies collide, though the stars in the galaxy are extremely unlikely to collide with each other, the gas and dust in the galaxy get compressed and heated by the collision. This compression and heating causes more star formation, which can be detected by looking for emission by particular molecules like CO and H_2O.

Over billions of years, mergers of small galaxies can result in the giant galaxies we see today. Studies of Arp 220 are important for understanding distant galaxies and galaxy formation in the early universe.

The inset optical image of Arp 220 was made with the Hubble Space Telescope.

Credit: ESA/Herschel/SPIRE "Nearby Galaxies" consortium and NASA/ESA/STSci (inset).

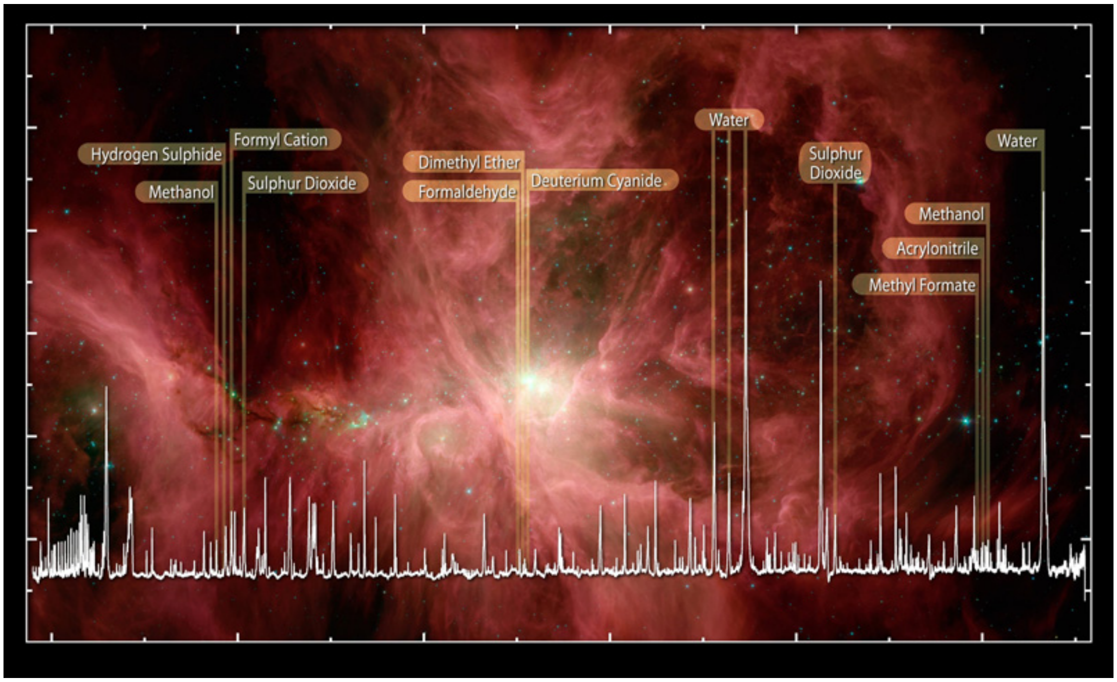


Above is real data from the High Resolution Camera (HRC) and the Low Energy Transmission Grating Spectrometer (LETGS) on the Chandra satellite. Chandra has nested X-ray mirrors that resemble glass barrels; they are designed this way so that incoming X-rays just graze the mirrors so they can be focused. The LETGS is an assembly that is swung into position behind the mirrors where it intercepts the reflected X-rays. The X-rays are diffracted by LETGS, which changes their direction an amount dependent on the energy of the X-ray, just like a prism separates light into its component colors. The HRC, located at the focal point of the telescope, can then detect the location of the X-ray on the detector and also measure its energy.

This X-ray spectrum (or graph of intensity of light over wavelength) is of the central region of the galaxy NGC 5548, and it gives astronomers information about the gas around the giant black hole in the center of the galaxy. The deep valleys in the spectrum (called absorption lines) are produced when warm (few million degree) gas absorbs X-rays of specific energies from hotter gas close to the central black hole, and are due to the presence of elements like carbon, nitrogen, oxygen, neon and magnesium. A peak in the spectrum due to emission from oxygen is also identified. The lines are slightly shifted to shorter wavelengths because the gas is moving away from the black hole at about a million kilometers per hour.

Credit: NASA/SRON

Large -> Exoplanets -> IR -> Spectrometer - Single Primary



Above is real data from the Heterodyne Instrument for the Far Infrared (HIFI) on the European Space Agency's Herschel satellite, a far-infrared and submillimeter mission that at the time of its launch in 2009, was the largest telescope to be put into space. Showing intensity of light over far-infrared wavelength, the spectrum has a dense pattern of "spikes", each representing the emission of light from a specific molecule in the Orion Nebula, a nearby stellar nursery. Among the organic, life-enabling molecules identified in this spectrum are water, carbon monoxide, formaldehyde, methanol, dimethyl ether, hydrogen cyanide, sulphur oxide, and sulphur dioxide.

One of the goals of the HIFI instrument is to investigate the role of water in the formation of stars and planets. Spectra like this one can go beyond the study of star formation to understanding the chemistry associated with the birth of stars, planets, and life.

The background image is from the infrared Spitzer Space Telescope.

Credit: ESA, HEXOS and the HIFI consortium, (background) NASA/Spitzer

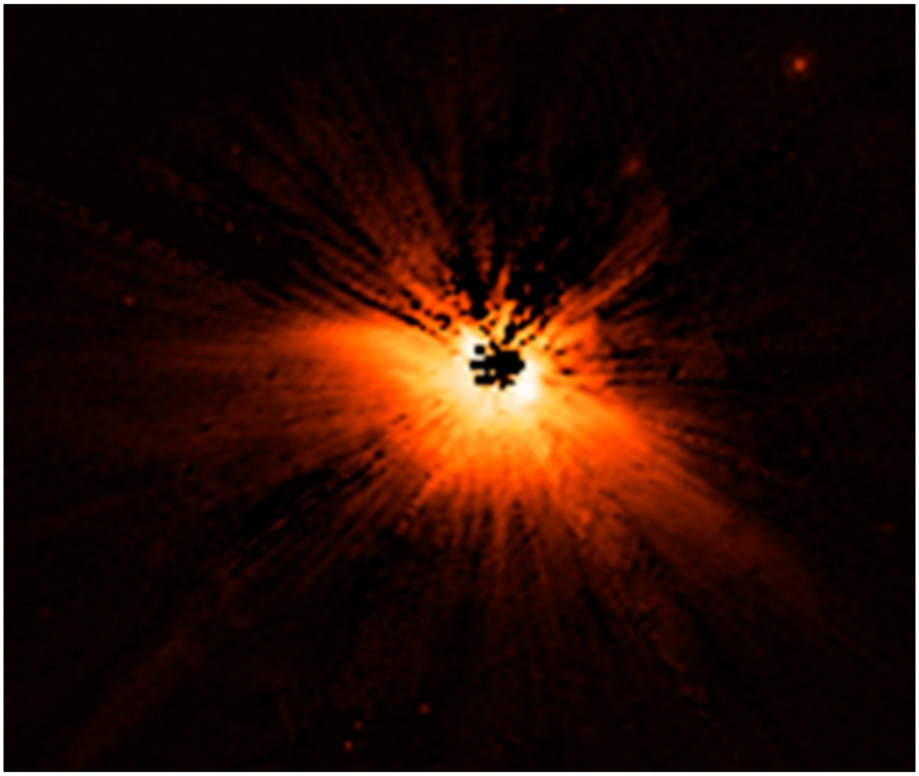
Large -> Exoplanets -> IR -> Spectrometer - Segmented
Large -> Exoplanets -> IR -> Camera - Segmented

Real data from a large, infrared space telescope with a segmented mirror does not yet exist, though it will in the near future. Currently under construction is the James Webb Space Telescope, an infrared mission with a segmented mirror 6.5 meters (21 feet 4 inches) in diameter, made out of light-weight beryllium. (In comparison, the Hubble Space Telescope's glass mirror is 2.4 meters in diameter.) As an infrared telescope, Webb will be able to unravel the birth and early evolution of stars and planets by peering into the hearts of dense and dusty cloud cores where star formation begins. Webb's superior imaging and spectroscopy capabilities will allow us to study stars as they are forming in their dusty cocoons. It will also be able to study planet-forming disks around stars and study organic molecules that are important for life to develop.

The above image is from a computer model. Represented is a protostar deep within the cold, turbulent cocoon of a molecular cloud which hosts a dusty disk where brown dwarfs or planets may one day form. Webb will be able to make observations of stars with dusty disks and young solar systems in the near- and mid-infrared, hunting for planets and probing the regions interior to the dust ring for structures like an inner asteroid belt. With Webb currently under construction, space telescopes with giant mirrors are becoming a reality; astronomers are eager to see the spectacular data the next generation of telescopes, like Webb, will produce.

Credit: NCSA/NASA/A. Kritsuk and M. Norman (UC San Diego) and A. Boley (Univ. of Florida)

Large -> Exoplanets -> IR -> Camera -> Single Primary

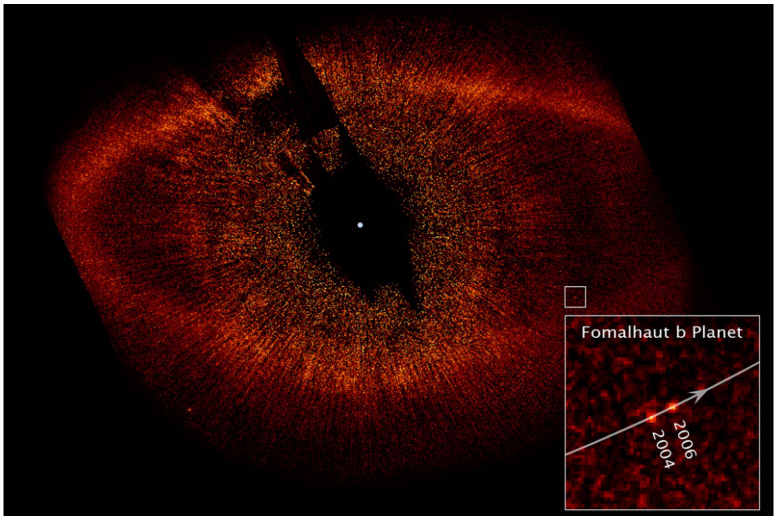


Above is real data from the Near-Infrared Camera and Multi-Object Spectrometer (NICMOS) aboard NASA's Hubble Space Telescope. The image shows the dust disk surrounding the young, nearby star HD 61005, also known as "The Moth" because the dust disk resembles the wings of the flying insect. The "wingspan" of The Moth extends about 22 billion miles from the star. The black disk in the center of the image is from a hole in the NICMOS camera that blocks most of the starlight so that astronomers can see details in the surrounding dust disk.

Dust disks around stars of The Moth's age (around 100 million years) are typically flat structures where planets can form, however, this Hubble image shows that some dust disks have unusual shapes. In the case of HD 61005, this may be because the star is moving through a patch of higher-density gas in the interstellar medium, causing its dust disk to be swept out behind. It is possible (but still unclear) whether the interaction between The Moth's dust disk and its environment could affect its prospects for planet formation, or have an effect on the atmospheres of evolving planets.

Credit: NASA, D. Hines (Space Science Institute, New Mexico Office in Corrales, New Mexico), and G. Schneider (University of Arizona)

Large -> Exoplanets -> Optical -> Camera - Hubble ACS



Above is real data from the Advanced Camera for Surveys (ACS) onboard the Hubble Space Telescope. This is the first visible-light snapshot of a planet, which is named Fomalhaut b, for its parent star, Fomalhaut. The planet is shown as a red dot, which is outlined by a white square.

In 2004, the ACS showed that this star has a large dust belt, or ring of protoplanetary debris, that is approximately 21.5 billion miles across. This large debris disk is similar to the Kuiper Belt, which encircles the solar system and contains a range of icy bodies from dust grains to objects the size of dwarf planets, such as Pluto. Another observation 21 months later (inset image) showed that Fomalhaut b was indeed moving on a path around the star and and that it would take 872 Earth years to orbit the star once. This planet is located 10.7 billion miles from its star, about 10 times the distance of Saturn from the Sun. The planet is having a gravitational influence on its surroundings, shaping the disk of dust it orbits within, giving it a sharp inner edge. Likewise, the inner edge of our solar system's Kuiper Belt is similarly shaped by the gravitational influence of Neptune. Fomalhaut b's mass was determined to not be any more than three times the mass of Jupiter or its gravity would have destroyed the dust belt altogether. The planet is brighter than expected for its mass - one possibility is that it has a huge Saturn-like ring of ice and dust reflecting starlight, which might eventually coalesce to form moons.

This planet's parent star is much hotter than our sun and is 16 times as bright. This means it has the potential for a solar system much larger in scale than ours. However, Fomalhaut is burning its hydrogen at such a fast rate that it will burn out in only 1 billion years, a tenth of the lifespan of our Sun. This means there is little opportunity for advanced life to evolve on any habitable worlds the star might possess. Future observations will attempt to see the planet in infrared light and will look for evidence of water vapor clouds in the atmosphere. An infrared telescope with a large, segmented mirror, like the under-construction James Webb Space Telescope, might be able to learn more about the evolution and composition of this young planet.

Credit: NASA, ESA, P. Kalas, J. Graham, E. Chiang, E. Kite (University of California, Berkeley), M. Clampin (NASA Goddard Space Flight Center), M. Fitzgerald (Lawrence Livermore National Laboratory), and K. Stapelfeldt and J. Krist (NASA Jet Propulsion Laboratory)

Large -> Exoplanets -> Optical -> Spectrometer - Segmented
Large -> Exoplanets -> Optical -> Camera - Segmented

Real data from a large visible-light space telescope with a segmented mirror does not yet exist, though it is now technologically possible to build one. Currently under construction is the James Webb Space Telescope, an infrared mission with a segmented mirror 6.5 meters (21 feet 4 inches) in diameter, made out of light-weight beryllium. (In comparison, the Hubble Space Telescope's glass mirror is 2.4 meters in diameter.) Though it will see primarily in the infrared, Webb will be able to detect red and gold visible light, and Webb's segmented, deployable design could be used to build a telescope optimized for visible light.

The above image is from a computer model. Represented is a protostar deep within the cold, turbulent cocoon of a molecular cloud which hosts a dusty disk where brown dwarfs or planets may one day form. Webb will be able to make observations of stars with dusty disks and young solar systems in the near- and mid-infrared, hunting for planets and probing the regions interior to the dust ring for structures like an inner asteroid belt. With Webb currently under construction, space telescopes with giant mirrors are becoming a reality; astronomers are eager to see the spectacular data the next generation of telescopes, like Webb, will produce.

Credit: NCSA/NASA/A. Kritsuk and M. Norman (UC San Diego) and A. Boley (Univ. of Florida)